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ON THE HYPOTHESIS OF CONSTANT ATOMIC RADII

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Introduction.—It has been suggested[1] that the data from the study of crystal structures are in agreement with an hypothesis which assigns to the atoms of each element a definite size and builds up crystals through their packing together. The structures of many more crystals have been determined since this hypothesis was first advanced and information has arisen from some of these which does not accord with the idea of constant atomic radii. For this reason, and also because various discussions of "shapes" of atoms based upon the assumption of its correctness have appeared, a reëxamination of the question in the light of the best data now available is required.

A knowledge of its precise status is also of importance to the crystal analyst because the agreement of such a simple hypothesis with results of experimentation would make possible the location of the atoms in crystals whose structures are far too complicated for complete study by existing X-ray methods.

The Calculation of Atomic Radii.—Calculation of the "sphere of influence" of atoms can now be made from four independent starting points: (1) from metals; (2) through the diamond and divalent metal carbonates of the calcite group; (3) from pyrite (FeS_2); (4) with the aid of cesium dichloro-iodide ($CsCl_2I$). If atomic radii are strictly constant all of these approaches should lead to the same result. It has been quite clear for some time, however, that the metals do not fit well into this scheme. Calcite and its related minerals likewise present difficulties because of the two different assignments of position which have been made to the oxygen atoms. The results from pyrite and cesium dichloro-iodide are

in substantial agreement and have therefore been chosen as offering the basis for the fairest test of this hypothesis. Of these last two cesium dichloro-iodide is the most practicable for use as a primary standard because crystals containing halogen atoms have been most studied while few sulfides have as yet been investigated. It is of course evident that the conclusiveness of the test of this hypothesis is not concerned with the precise absolute value of the atomic radii so long as conflicting standards are not used simultaneously. Consequently the conclusions which may be drawn from the work which follows would not be invalidated if the chlorine atom which will appear as primary standard were given a somewhat different size.

Starting from cesium dichloro-iodide the following procedure has been employed in calculating atomic radii. The distance along a trigonal axis from an atom of cesium through one of chlorine to an iodine atom is 6.102 Å. U. The nearest approach of cesium and iodine atoms in crystals of cesium iodide is 3.94 Å. U. The diameter of the chlorine atom may then be taken directly as the difference between these two distances or 2.162 Å. U. From this initial value radii are calculated for other atoms either from the most adequately studied compound available or, as in the case of the alkali halides, through an averaging of several of these values. The radii thus obtained for the electronegative atoms for which comparative data exist are as follows:

ATOM	"RADIUS"	ATOM	"RADIUS"	ATOM	"RADIUS".
H	0.55 Å. U.	Br	1.24[5] Å. U.	N	0.62[6] Å. U.
F	0.62[1]	I	1.50[1]	O	0.64
Cl	1.08[1]	(CN)	1.22	S	1.04[3]

Comparisons between calculated and observed interatomic distances which are, respectively, favorable to or in disagreement with the hypothesis of constant radii are collected in tables 1 and 2.

TABLE 1

DATA THAT ACCORD WITH AN HYPOTHESIS OF CONSTANT ATOMIC RADII

		INTERATOMIC DISTANCES	
CRYSTAL	BETWEEN ATOMS	CALCULATED	OBSERVED
Li	Li–Li	3.00Å. U.	3.03Å. U.
LiH	Li–H	(2.05)	2.05
LiF	Li–F	2.12	2.07; 2.01
LiCl	Li–Cl	2.581	2.585
LiBr	Li–Br	2.746	2.74
LiI	Li–I	3.00	3.03
NaF	Na–F	2.35	2.34; 2.305
NaCl	Na–Cl	(2.814)	2.814
NaBr	Na–Br	2.976	2.975; 3.01

NaI	Na–I	3.23	3.235; 3.25
$NaNO_3$	Na–O	2.37 (if u = 1/4)	2.388
KF	K–F	2.676	2.68; 2.69
KCl	K–Cl	3.136	3.13
KBr	K–Br	3.301	3.30
KI	K–I	3.556	3.55
KCN	K–(CN)	(3.27)	3.27
RbCl	Rb–Cl	3.30	3.30
RbBr	Rb–Br	3.466	3.465
RbI	Rb–I	3.72	3.68; 3.654
CsF	Cs–F	3.06	3.015
CsCl	Cs–Cl	3.52	3.568
CsBr	Cs–Br	3.686	3.724; 3.713
CsI	Cs–I	(3.94)	3.94; 3.966
MgO	Mg–O	(2.10)	2.10
$Mg(OH)_2$	Mg–O	2.10	2.09 (probably)
CaF_2	Ca–F	(2.368)	2.368
CaO	Ca–O	2.387	2.384
$CaCO_3$	Ca–O	2.387 (if u = 1/4)	2.372
BaO	Ba–O	(2.74)	2.74
BaF_2	Ba–F	2.72	2.684
ZnS	Zn–S	(2.337)	2.337
ZnO	Zn–O	1.934	1.942
Cu_2O	Cu–O	(1.845)	1.845
CuCl	Cu–Cl	2.286	2.377; 2.32
CuBr	Cu–Br	2.451	2.52; 2.49
CuI	Cu–I	2.706	2.64; 2.63
AgCl	Ag–Cl	2.725	2.78; 2.76
AgBr	Ag–Br	(2.89)	2.89
Ag_2MoO_4	Ag–O	2.284	2.315
$CaCO_3$	C–O	(1.245)	1.245 (if u = 1/4)
$MnCO_3$	C–O	1.245	1.275 (if u = 0.27)
Sn (gray)	Sn–Sn	2.734	2.798
K_2SnCl_6	Sn–Cl	(2.448)	2.448
$(NH_4)_2SnCl_6$	Sn–Cl	2.448	2.462
Ag_2MoO_4	Mo–O	(2.00)	2.00
Mo	Mo–Mo	2.72	2.72; 2.668
FeS_2	Fe–S	(2.254)	2.254
Fe	Fe–Fe	2.422	2.476
Fe_3O_4	Fe^{II}–O	1.851	1.797
MnS	Mn–S	(2.607)	2.607
$MnCO_3$	Mn–O	2.204	2.17 (if u = 0.27)
$Mn(OH)_2$	Mn–O	2.204	2.08–2.26 (2.19 is best)
K_2PtCl_4	Pt–Cl	(2.27)	2.27
$(NH_4)_2PtCl_6$	Pt–Cl	2.27	2.16–2.36
K_2PdCl_4	Pd–Cl	(2.29)	2.29
$(NH_4)_2PdCl_4$	Pd–Cl	2.29	2.34 (approximately)

NOTE.—The references for the crystal dimensions used in preparing this and the following table can be found in a recent paper by the writer (*J. Frank. Inst.*, Feb., 1923). The numbers enclosed in parentheses have been used directly in calculating values for "atomic radii."

TABLE 2

DATA DISAGREEING WITH AN HYPOTHESIS OF CONSTANT ATOMIC RADII

CRYSTAL	BETWEEN ATOMS	INTERATOMIC DISTANCES CALCULATED	OBSERVED
Na	Na–Na	3.46 Å. U.	3.724 Å. U.
K	K–K	4.11	4.504
$K_2Zn(CN)_4$	K–(CN)	3.27	3.14
K_2PtCl_4	K–Cl	3.136	3.227
K_2PdCl_4	K–Cl	3.136	3.23
K_2SnCl_6	K–Cl	3.136	3.48
$CsCl_2I$	Cs–Cl	3.52	3.65
$CsCl_2I$	Cs–I	3.94	4.18
Be	Be–Be	(2.234)	2.234
BeO	Be–O	1.757	1.648 and 1.65 (if $u=5/8$)
Mg	Mg–Mg	2.92	3.22
Ca	Ca–Ca	3.494	3.926
Zn	Zn–Zn	2.588	2.93 (if $u=1/2$)
$K_2Zn(CN)_4$	Zn–(CN)	2.514	2.715
Cd	Cd–Cd	3.44	3.30 (if $u=1/2$)
CdO	Cd–O	(2.36)	2.36
$K_2Cd(CN)_4$	Cd–(CN)	2.94	2.80
CdI_2	Cd–I	3.22	2.98
Cu	Cu–Cu	2.41	2.542
Ag	Ag–Ag	3.288	2.866
Ag_2O	Ag–O	2.284	2.06; 2.04; 2.03
AgI	Ag–I	3.145	2.81 and 2.825
Diamond	C–C	1.21	1.542
Si	Si–Si	2.194	2.352
$(NH_4)_2SiF_6$	Si–F	(1.718)	1.718
$NaNO_3$	N–O	(1.266)	1.266
NH_4Cl	N–H–Cl	2.807 [3.34]	3.342
NH_4Br	N–H–Br	2.972 [3.507]	3.454
NH_4I	N–H–I	3.227 [3.76]	3.60
$NiCl_2.6NH_3$	N–H–Cl	2.807 [3.34]	3.56
$NiBr_2.6NH_3$	N–H–Br	2.972 [3.507]	3.70
$NiI_2.6NH_3$	N–H–I	3.227 [3.76]	3.89
$(NH_4)_2PdCl_4$	N–H–Cl	2.807 [3.34]	3.328
$(NH_4)_2PtCl_6$	N–H–Cl	2.807 [3.34]	3.48
$(NH_4)_2SnCl_6$	N–H–Cl	2.807 [3.34]	3.54
$N_2H_6Cl_2$	N–H–Cl	2.807	3.143
$CsCl_2I$	Cl–I	2.582	2.23–2.29 (if u=0.312–0.317)
CdI_2	I–I	3.00	4.206
Fe_3O_4	Fe^{III}–O	1.85	2.07
NiO	Ni–O	(2.085)	2.085
Ni	Ni–Ni	2.89	2.50
$NiCl_2.6NH_3$	Ni–NH	2.07 or 3.17	2.29–2.47
Pt	Pt–Pt	2.378	2.77; 2.838
Pd	Pd–Pd	2.418	2.788; 2.754

NOTE.—The second column under calculated distances (enclosed in brackets) gives distances which are calculated upon the assumption of a definite but large volume for the ammonium group.

The many examples of table 2 show clearly and conclusively that the simple hypothesis which assigns a definite size to each atom and builds up crystals by packing these atoms together is not in harmony with experiment.

The fact that such metals as zinc and cadmium crystallize with an axial ratio which is considerably removed from that corresponding to the closest packing of spheres might suggest[2] that the original hypothesis could be modified by assigning to each atom a definite shape. Atoms thus might have different atomic radii depending upon their orientation within the crystal. This sort of a modification fails to account, for example, for the increasing separation between alkali and halogen atoms in such complex halides as the chloroplatinites and chloroplatinates or for the observation that silver, which shows very different radii in silver chloride and silver iodide, nevertheless crystallizes in the cubic close packing of spheres.

From the little that is known of the complexities of atomic structure it would be most surprising to find an hypothesis of constant atomic radii, or any simple modification of it, in accord with experiment. It will, nevertheless, be noted that a rule of constant atomic radii appears to hold true within such large groups of isomorphous compounds composed of two kinds of atoms as those alkali halides which have the sodium chloride arrangement. This may be interpreted to mean that as long as the number and distribution of one kind of atom about the other remain the same, the interatomic distances are additive in passing from crystal to crystal. When the atomic arrangement is closely alike in two crystals the corresponding interatomic distances may also not be greatly different. Thus each silver atom in silver molybdate is surrounded, as in the sodium chloride arrangement, by six oxygen atoms and the distance from silver to oxygen is calculable from the interatomic distances in the sodium chloride-like silver chloride or bromide.

The experimental data show that whenever the atomic environment (meaning thereby the manner of arrangement of atoms of one kind about those of the other) is changed, the corresponding interatomic distances are also varied. It is to be anticipated that the exact manner of change of interatomic distances with atomic environment will be understood only when knowledge of atomic structure has so far progressed that a calculation of the stabilities of different atomic arrangements is possible. In the meantime some working rules of a qualitative nature may be developed; but the existing crystal structure data are not adequate to establish them.

Conclusion.—From the crystal structure data which are presented in table 2 it must be concluded that the hypothesis of constant atomic radii is not in agreement with existing information. These data, however, conform to the rule that in isomorphous crystals composed of only two

kinds of atoms the interatomic distances have additive properties which can be illustrated through a summing up of "atomic radii." The data also show that for compounds of different crystal structures in which the atomic environments are different the interatomic distances likewise are unlike. Where the changes of environment are relatively small this change in interatomic distance may be almost negligible; in other cases it amounts to several tenths of an Ångstrom unit.

[1] W. L. Bragg, London, *Phil. Mag.*, **40**, 1920 (169).

[2] For instance see W. P. Davey, *Physic. Rev., Ithaca*, **19**, 1922 (248).

PHOTOGRAPHIC DETERMINATION OF PARALLAXES WITH THE 100-INCH REFLECTOR

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In the issue of these PROCEEDINGS for April, 1915, were communicated the first results of parallax determinations with the Mount Wilson 60-inch reflector. The work has progressed steadily until now over 170 objects have been measured. The probable errors as well as the systematic errors are small, viz., $\pm 0''.0056$ and $-0''.0024$. On account of the difficulty in guiding at the Cassegrain focus on stars of southern declination, only a very few of these objects were placed on the observing program. Moreover, for several very faint stars and for stars in extremely poor fields it became necessary either to increase the exposure-time, which as a rule was fifteen minutes, or to use another instrument. A trial was accordingly made with the Newtonian arrangement of the 100-inch Hooker telescope (focal length 42 feet).

For four fields the plates have now been measured and reduced; the results are as follows:

OBJECT	PG. MAG.	α 1900 H.	M.	S.	δ 1900	π REL.	P. E.
Wolf 1037	14.5	22	23	44	+ 5° 20′	+0″.054	±0″.004
Wolf 1039	13.8	23	29	2	− 0° 21′	+0.056	0.004
Wolf 1040	14.5	23	31	37	+ 0° 37′	+0.057	0.007
N.G.C. 7293	13.3	22	24	18	−21° 21′	+0.058	±0.005

The first three stars have very large proper motions, which according to Wolf are $1''.57$, $1''.44$ and $1''.23$ annually. From the parallaxes derived here, they appear to be stars of very faint absolute magnitude, about +13

photographic while their velocities at right angles to the line of sight are about 110 km./sec.

The last object in the table is the so-called Helical nebula, which is the giant among the planetary nebulae, with a major axis of 15′, corresponding to 3,500,000,000,000 kilometers, if the above parallax is used. The diameter of this object is thus 375 times that of our solar system (orbit of Neptune). The central star has an absolute magnitude of +11.2.

Aside from possible systematic errors, for which at present there is no evidence, the results are extremely satisfactory, the mean probable error of a parallax being only ±0″.005.

LIGHT AND COLOR VARIATIONS OF NOVA AQUILAE 1918.4

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The new star originally designated as Nova Aquilae, No. 3, and according to the new nomenclature[1] called Nova Aquilae 1918.4, was the brightest nova for more than three centuries. It was discovered early in June, 1918, by a hundred or more different observers. Three separate investigations of the star were begun immediately at the Harvard Observatory.

Visual observations of the nova were made by Mr. Campbell and others at Cambridge, and also were collected at Harvard in large numbers from many observers in all parts of the world. The spectrum was studied by Miss Cannon on more than one hundred spectrograms made with various telescopes at Cambridge and at the Harvard Station at Arequipa, Peru. The photographic light curve was investigated under the direction of Miss Leavitt, using mainly Harvard photographs.

The first two parts of this investigation of the nova have already been published in Volume 81 of the Harvard Annals, and the third part will soon appear as the final number of that volume.

A general summary of all the work is given below.

1. Photographs of the region obtained at the Harvard, Heidelberg and Yerkes Observatories show that the nova was a star between the tenth and eleventh magnitudes for at least thirty years before its discovery, with small, but well-confirmed, changes in light. Its spectrum at that time is placed by Miss Cannon somewhere near Class A, which would indicate that its absolute magnitude probably was not fainter than +3.5

before the outburst. If we accept this value, we find that the logarithm of the parallax, $\log \pi = 0.2(3.5 - 10.5 - 5)$, is not greater than -2.4, and the parallax is less than 0.004, corresponding to a distance greater than 800 light years. And further, since the total variation was nearly twelve magnitudes, the absolute brightness of the nova at maximum was in excess of magnitude -8, making this one of the most highly luminous objects ever recorded.[2]

2. The rise in brightness began on June 7, 1918. The maximum was reached, at visual magnitude -1.2, two days later when the object for a time was brighter than any star in the sky except Sirius, being forty thousand times brighter than it was the week before. In the four years that have elapsed since the outburst, the nova has decreased in brightness to the tenth magnitude, and is now but slightly brighter than before June, 1918.

3. More than six thousand observations by two hundred and forty-eight observers were utilized in deriving the Harvard visual light curve. The observers were distributed as follows: North America 87, South America 3, Europe 132, Asia 8, Africa 5, Australasia 13.

4. From June 9 to June 25 the star decreased four magnitudes in brightness. Then it entered into remarkable series of semi-periodic fluctuations that lasted for nearly four months, while gradually the average brightness decreased two magnitudes. Since October, 1918, the nova has decreased five magnitudes more, with only minor irregularities.

5. Changes in the spectrum of the nova near maximum and during the oscillations on the descending branch were extremely complicated. They were characterized by the appearance of enhanced lines of iron and titanium during the rapid increase in light, later by the typical nova spectrum with its broad, bright and dark bands, and finally with the gradual predominance of the usual nebular lines.

6. The changes in the photographic light curve much resemble those of the visual light curve. For its determination more than a thousand photographic observations are available, nearly all of which were made on plates taken with half a dozen telescopes at Harvard.

7. A comparison of the photographic and visual light curves gives an indication of the color changes during the first few months of the star's activity. The color index remained slightly negative during the first five months, and then became positive as the star grew redder and fainter.

[1] *Trans. Internat. Astron. Union, London*, **1**, 1922 (89).

[2] *Cf.* Lundmark, *Pub. Astron. Soc. Pacific, San Francisco*, **34**, 1922 (209).

A THEORY OF THE HALL EFFECT AND THE RELATED EFFECT FOR SEVERAL METALS

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Forty-three years ago last October, in the physical laboratory of Johns Hopkins University, I discovered the electro-magnetic effect, or "phenomenon," which has ever since been called by my name. In the course of eight or ten years thereafter three other effects, related to this one, were detected and were named, respectively, after their discoverers, Ettingshausen, Nernst and Leduc. The last is sometimes called the Righi effect, Righi having found it independently.

Figures 1–4 will probably not be superfluous. In each we have

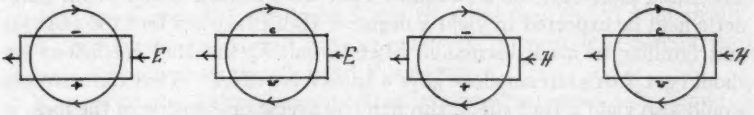

FIGURE 1 — Hall effect, R or ${}_eT_e$, positive.

FIGURE 2 — Ettingshausen effect, P or ${}_eT_h$, positive.

FIGURE 3 — Nernst effect, Q or ${}_hT_e$, positive.

FIGURE 4 — Leduc effect, S or ${}_hT_h$, positive.

a current, in 1 and 2 a current of electricity, E, in 3 and 4 a current of heat, H, flowing from right to left through a plate of metal placed at right angles with the lines of force of a magnetic field, the generating current of which runs clockwise. Conditions 1 and 2 may exist together, and so figures 1 and 2 might be superposed, though a negative Ettingshausen effect may go with a positive Hall effect, and vice versa. A like statement holds for 3 and 4. The alternative symbols, for example, ${}_eT_e$, are descriptive, the T meaning *transverse*, the initial subscript telling the nature of the longitudinal flow, the final subscript the nature of the transverse effect.

The various effects are mathematically defined as follows:[1]

$$R = \frac{\delta_e}{HI} \quad (1); \qquad P = \frac{\delta_h}{HI} \quad (2); \qquad Q = \frac{\delta_e}{H\Delta} \quad (3); \qquad S = \frac{\delta_h}{H\Delta} \quad (4)$$

It is easy to account for a negative Hall effect as due to the transverse push of the magnetic field on a free electron stream within the metal plate, but a positive Hall effect is harder to explain, though various attempts in this direction have been made by Sir J. J. Thomson and others. I have a theory, more or less plausible, of the positive action, but in this paper I shall not undertake to give it.

In fact, I shall for the present confine my attention to metals having a negative R, and the only ones of this description for which I have satisfactory data (except bismuth, in which, as in the obviously crystalline metals generally, there is probably some effect not to be reached by the theories of this paper) range themselves in two groups: first, copper, gold and silver, in each of which all four of the effects are negative; and, second, aluminium, nickel, palladium and platinum, in each of which S, as well as R, is negative, while P and Q are positive. My theory of the transverse effects in these seven metals has the very closest relation to the theory of dual electric conduction, and the attendant theory of thermal conduction, which I have been setting forth in these PROCEEDINGS during the last four or five years.[2]

Let us see first what comes from the dual nature of electric conduction, the existence of two streams, one of free electrons, the f stream, the other of associated electrons, the a stream. That the f stream would in the magnetic field be expected to yield a negative Hall effect is a fact too obvious and familiar to need discussion. Let us call R_f the Hall coefficient we should get if this stream alone gave a transverse effect. That the a stream would also yield a Hall effect, through transverse orientation of the ions, is not so obvious, and in due time I must support this thesis by argument, but in this paper I have not space for this demonstration. Let R_a be the Hall coefficient we should get if this stream alone gave a transverse effect.

But the two Hall effects thus provided for would not, in general, be equal. What, then, should be the result of the two tendencies? Something closely analogous to that happens when two galvanic cells of different e. m. f. are joined in opposition as in figure 5. Here a cyclic current flows, clockwise if E_1 is greater than E_2, counter-clockwise if E_2 is the greater, while the potential of point A is in either case less than that of point B.

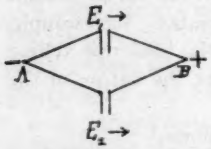

FIGURE 5

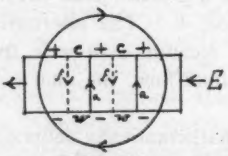

FIGURE 6

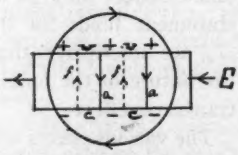

FIGURE 7

So within the plate of figure 6 or figure 7 there is a transverse cyclic current, the f transverse stream crossing the plate in one direction, the a transverse stream in the opposite direction, the direction of the cyclic motion depending on the relative magnitudes of R_f and R_a.

It is easy to find from theory an expression for R_f. I get

$$R_f = -(6.28\, d' \times x) \div k\, T^{0.5}. \qquad (5)$$

In this equation x is such a quantity that $l_0 = x\,(1 \div \nu^{1/3})$, (6)

l_0 being the mean path of free electrons at 0° C. and ν the number of atoms per cu. cm.; so that $(1 \div \nu^{1/3})$ is approximately the centre to centre distance of adjacent atoms and may for short be so called. The quantity d' is a variable such that $d' \times x$ is the length of mean free path at any temperature T; k is the specific conductivity of the metal, equal to $k_a + k_f$.

The value of R_a cannot be found without information to be obtained from the Hall effect observations themselves. It is related to the observed value of R and the calculated value of R_f by the equation

$$R = R_a\, k_a/k + R_f\, k_f/k. \qquad (7)$$

Here R corresponds to potential of B less potential of A in figure 5, while R_f corresponds to E_1, let us say, and R_a to E_2.

Figure 6 shows a case in which R_f is greater than R, numerically, and the f transverse current goes downward across the plate while the a transverse current goes upward. In figure 7 the R_f is less than the R, numerically, and the f transverse current goes up while the a transverse current runs down. In both cases the observed R is negative.

Now as to the Ettingshausen effect in these two cases. In figure 6 the free electrons combine with ions to form atoms at the lower edge of the plate, and heat is given out by this process, warming the plate in this region, while at the upper edge ionization is constantly going on, absorbing heat and cooling the plate locally. Thus we have a *positive* Ettingshausen effect combined with a negative Hall effect. In figure 7 the transverse thermal conditions are evidently opposite to those of figure 6 and so we have here a negative Ettingshausen effect, combined with a negative Hall effect.

Equilibrium in either case is reached when the transverse gradient becomes just great enough to carry back across the plate, by ordinary thermal conduction, the heat that is generated at one edge by the cyclic electric current. Let us assume that I, H, and the width of the plate, are each unity. Then the condition of equilibrium is expressed by the equation

$$P\theta = (R - R_f)k_f\lambda, \qquad (8)$$

or by use of (5)

$$P\theta = \left(R + \frac{6.28\, d'}{k\, T^{0.5}}\, x\right) k_f \lambda. \qquad (9)$$

In these equations θ is thermal conductivity in ordinary measure, and λ is the number of calories required to free $(1 \div e)$ electrons within the metal. My previous papers have given me the means of calculating k_f and λ for many metals, and I have a way of finding d'. Thus equation (9) gives me the means of determining x, which by means of equation (6) determines the length of mean free path at 0° C. Values of x ranging from about 4 to about 40 are found in this paper for the seven metals dealt with—that is,

values of mean free path, at 0° C., ranging from about 4 to about 40 times the centre to centre distance of adjacent atoms.

Though I have written and thus far discussed equation (8) as if the equilibrium represented by it were of the "mobile" sort, heat conduction constantly and actively undoing the constant thermal action of the transverse electric cyclic current, my conception of the mechanism of thermal conduction leads to the conclusion that the transverse temperature gradient tends of itself to set up a cyclic transverse electric current opposite in direction to the one that makes the temperature gradient, and that the equilibrium condition is really one of dead-lock, two virtual equal and opposite cyclic transverse currents really extinguishing each other, so that we have finally the paradoxical state of a transverse potential gradient with no transverse electric flow and a transverse temperature gradient with no transverse heat flow.

Using my previously developed theory of dual electric conduction and of thermal conduction, I have worked out a theoretical relation between the Hall effect and the Nernst effect which I shall here give without proof. Starting with the equation

$$Q = Q_a k_a/k + Q_f k_f/k, \tag{10}$$

which is strictly analogous to equation (7), I get by development an equation, which I shall call (11), too long to be given and discussed here, which contains our x as its only unknown quantity.

Of course, if the theory and all the data used were strictly accurate, the value of x obtained from (11) should be the same as that obtained from (9); in fact, the two equations do not, in any one of the four cases where comparison is thus far practicable, give just the same values of x, but in only one of these four cases is the ratio of the two values as great as 2, and a large part of the discrepancy can reasonably be attributed to inaccuracy of the experimental data, as will presently appear.

The relation of the Leduc effect, a transverse temperature gradient, to the Nernst effect, a transverse potential gradient, is precisely the same in form as the relation of the Ettingshausen effect to the Hall effect. It is given by the equation

$$S\theta = (Q - Q_f) k_f \lambda, \tag{12}$$

which is to be compared with (8). An expression for Q_f, containing x, is found in (11). The values of Q and S being known by direct experiment, we thus have a third method of determining x, and the value thus formed is in good agreement, due allowance being made for probable inaccuracy of data, with the values found from (9) and (11), respectively.

It is to be remembered that equations (9), (11) and (12) have, for the most part, been used with reference to a mean temperature of 0° C. That

TABLE I

METAL		HALL R or ${}_eT_e$	ETTINGSHAUSEN P or ${}_eT_h$	x	NERNST Q or ${}_hT_e$	x	LEDUC S or ${}_hT_h$	x
Copper	$[U]$	-4.6×10^{-4}	-13.4×10^{-10}	29.8	-1.9×10^{-4}	38.8	-2.1×10^{-7}	33.2
	$[U_0]$	-4.2 "	[-16.2 "]	38.1	-1.74 "	35.2	-2.5 "	41
		-5.2 "			-0.9 "		-1.4 "	
Gold	$[L]$	-7.4 "	-16 "	33.8	[-2.8 "]	33.8	[-2.9 "]	33.8
		-6.6 "						
Silver	$[U]$	-5.1 "	-10 "	22.8	-1.8 "	40.3	-2.7 "	37
	$[L]$	-8.1 "	-12 "	36.4	[-10.8 "]	36.4	[-2.8 "]	36.4
Alumin.	$[U]$	-2.78 "	$+7.8$ "	9.8	$+0.42$ "	17.3	-6.6 "	9.9
Nickel[1]	$[U]$	-38.0 "	$+390$ "	57 5	$+10.0$ "	129	-2.5 "	74
	$[U_0]$	-34.0 "	[$+1000$ "]	81	-0.5 "	77	-2.8 "	84.5
Pallad.	$[L]$	-8.3 "	$+99$ "	13.8	[1.9 "]	13.8	[-1.2 "]	13.8
		-6.9 "			$+1.27$ "		-0.33 "	
		-11.1 "			$+0.5$ "		-0.18 "	
Platin.	$[L]$	-1.4 "	$+34$ "	3.75	[$+0.55$ "]	3.75	[-0.26 "]	3.75
		-2.4 "					-0.21 "	

[1] Apparently the values of R, P, etc., given by Unwin for nickel were obtained with a very powerful magnetic field, about 22,000. The strength of the field is not very important in case of the other metals here dealt with.

It is to be noted in the second nickel line that P, obtained by use of equation (9), with R taken as -34 and x as 81, and Q, found by reduction from a value observed at a higher temperature, have opposite signs. I believe that this, if it is a genuine case of such difference, is the only one known, though I expect that others will be found.

is, values of k, λ, l, etc., have been taken with reference to this temperature; but observations of R and P have usually been taken at or near room temperature, values of Q and S in the neighborhood of 50° C., and I have in most cases left these as found, not knowing well the laws of their variation with temperature. For copper and nickel, however, I have the means of reducing the observed values of R, Q, and S, but not P, to what they would be at 0° C., and the effect of this reduction is, in the case of nickel at least, important and beneficial, as will be seen a little farther on.

In table I the results of observations and calculations are brought together. Where the three x's in one horizontal line are all alike the value is found from the Hall and Ettingshausen effects alone, there being no available observed values of Q and S in these cases. The numbers given in [ ] are values of P, Q or of S found by calculation from equation (9), equation (11) or equation (12), according to circumstances, by use of a predetermined value of x, found from observation data given elsewhere on the same horizontal line. All the other values given in the table are from direct observations of R, P, Q and S, respectively, reduced in certain indicated cases to 0° C.

The $[U]$ means that the observations following on the same horizontal line were made by Mr. F. Unwin,[3] who, I think, used the same piece of metal for all four effects. From him alone I have complete data that seem usable for any metal in the list here given. The $[U_0]$ indicates Unwin values of R, Q and S, reduced to 0° by means of information given by Unwin. The $[L]$ means that the values of R and P following on the same horizontal line were found by my assistant, Mr. N. C. Little, at the Jefferson Physical Laboratory, the same piece of metal being used for both effects. The metals used by Little were the purest that could be obtained. Mr. Unwin writes me that his metals were "not of any particular purity."

Values of R, etc., found by other observers, not here named, are given for comparison, partly to show how dubious even direct measurements of the quantities in question are. It is not, I think, claiming too much to say that the values in [ ], the values of P, Q and S obtained, respectively, from the values of other coefficients by calculation, compare very well in accuracy with those obtained by direct measurement.

[1] In these equations H is intensity of mag. field, I is intensity of long. elec. cur. (abs. units per sq. cm.), Δ is long. temp. grad., δ_e is trans. pot. grad. (abs.), δ_h is trans. temp. grad. Other definitions are sometimes given with sign conventions somewhat different from those of figures 1–4.

[2] See my *Summary*, these PROCEEDINGS for March, 1921; also October, 1922.

[3] *Proc. Roy. Soc. Edinburgh*, **34**, 1913–14 (209), and **41**, 1920–21 (44).

STUDIES OF SUBSPECIFIC HYBRIDS IN PEROMYSCUS*

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Communicated December 6, 1922

Three different crosses between geographic races of deermice (*Peromyscus*), yielding 347 F_1 and 296 F_2 individuals, have been studied in respect to 17 characters which are capable of quantitative expression. The characters in question are the lengths of the body, tail, foot, ear, pelvis, femur and skull; the indices of asymmetry (sinistro-dextral ratios) in respect to pelvis length, femur length, femur weight and jaw weight; the width of the tail stripe, depth of pigmentation of the foot, percentages of "black," "white" and "color" in the pelage, and finally the ratio of red to green in the color readings. Since both foot and pelvis are treated separately in the two sexes, we have 19 mean and standard deviations for each group of animals under comparison. The outstanding results of these experiments may be summarized as follows:

(1) The mean values for any given character in the hybrid animals usually lie between the parental values, though they are frequently not equidistant from the latter.

(2) On the other hand, the hybrid values may agree fairly closely with one or the other of the parental values, or they may lie beyond either of these.

(3) The means for the two hybrid generations frequently agree pretty closely with one another, though this is not the rule. There is a preponderant tendency for the F_1 figures to exceed those for the F_2 generation.

(4) No evidence of mendelian dominance has been found in respect to any single character.

(5) Considering all of the crosses here comprised, and all of the characters measured (57 pairs of contrasted figures), we may say that there is an undoubted tendency toward an increase in variability, as we pass from the F_1 to the F_2 generation.

(6) This increase is no greater (actually slightly less) when we compare the variability of characters in respect to which the parent races differ from one another than when we compare the variability of characters in respect to which the parents agree closely, or at least show no probable difference.

(7) This extension of variability in the second hybrid generation is exhibited most consistently of all, perhaps, in the case of the sinistro-dextral ratios of paired bones, although these ratios are known not to be hereditary at all.

(8) There is strong evidence that this increase of variability is not due to environmental factors resulting in a higher degree of abnormality in the F_2 generation.

(9) Coefficients of parent-offspring correlation, for all crosses and for all characters considered, average somewhat less than +.3. The mean coefficient expressing the correlation between F_1 parents and their F_2 offspring is +.306, which is somewhat greater than that expressing the correlation between the parent races and their F_1 offspring, but agrees very closely with some coefficients which were earlier computed for the pure races.

(10) The mean fraternal correlation is fairly large in both hybrid generations, being slightly (though not significantly) greater for the F_1 hybrids than for the F_2.

(11) Coefficients which have been computed for intra-individual correlation show that most of the characters which are associated together geographically (i.e., which vary together, as we pass from one subspecies to another) are, none the less, not appreciably correlated with one another in the individuals of any one subspecies. Nor do the subspecific characters which enter a cross together show any tendency to segregate together or even to vary together, in the F_2 generation, except in the case of those characters which are already correlated in the parent stocks.

Discussion.—While the results which are discussed in the present paper are not offered as an adequate refutation of the theory of "multiple factors," as applied to the differences between the subspecies of *Peromyscus*, they certainly depart rather widely, in some respects, from what we should have expected on the basis of that theory. In another paper,[1] I have likewise given reasons for doubting the origin of these subspecific differences through any such process of "mutation" as has been studied so intensively in the case of *Drosophila*, and various other animals and plants. It will probably be felt by many that my contentions, if sustained, would simply return the whole problem to the confusion in which it lay before the days of Mendel. It will doubtless seem that I have rejected the only scientific hypothesis which has been brought forward in explanation of these phenomena, without offering any other in its place.

At the outset, it should be replied that an incorrect hypothesis is not necessarily better than none. But, after all, the repudiation of the "multiple factor" theory does not necessarily involve the abandonment of any attempt at a scientific explanation of the phenomena at hand.

Even though we may refuse to postulate the existence of a series of special factors conjured up for the sole purpose of bringing our data into conformity with the generalized mendelian scheme of heredity, we may, none the less, see the direction in which a possible scientific explanation is to be sought. Surely the indisputable phenomena of maturation and fertiliza-

tion afford a general basis for an understanding of the relative variability of the two hybrid generations, without the need of postulating various entities whose existence is quite beyond the range of proof.

Thus it seems plain that every nucleus of an F_1 hybrid—between *sonoriensis* and *rubidus*, let us say—contains a full set of chromosomes derived from each one of the two races. Barring differences due to the somewhat mixed nature of both of the parent races, the F_1 hybrids are alike in their nuclear composition. But the random assortment of chromosomes, during the formation of the germ-cells of this generation, must bring it to pass that the F_2 individuals differ widely from one another in their nuclear composition, even if allowance be made for a large measure of interchange and mutual modification between the parent chromosomes.

Such an explanation is, of course, substantially identical with the neomendelian one up to a certain point. But it stops short of the latter in refusing to regard the entire heritage of an organism as the sum of a great number of independent and unalterable "factors" or "genes" of the type revealed by mendelian experiments. It has not been shown, for example, that these subspecific differences segregate with the chromosomes at all. It is not impossible that they undergo a total or partial blending during some phase of the nuclear cycle. The doctrine of the "individuality of the chromosomes" has already had to undergo serious modifications as a result of the phenomena of "crossing over," and it is possible that further serious curtailment is in store for it. There are strong reasons, too, for believing that the cytoplasm may play an important rôle in the transmission of certain parts of an organism's heritage.

In any case, one who keeps his mind open to such possibilities is not forced to call in question or to ignore results which do not seem in harmony with the more radical formulation of the factorial hypothesis. While, for example, the present writer can offer no explanation of the curious fact that we have a strong appearance of segregation in respect to certain characters which are not hereditary at all,[2] this fact stands in no contradiction to any hypothesis which he had previously adopted relative to the nature of hereditary transmission.

But I shall regard it as unfortunate if the value which is set upon the data contained in the present paper is made to depend wholly on their success in solving some of these fundamental problems of genetics. It must be remembered that almost nothing has hitherto been ascertained regarding the behavior of the subspecific characters of mammals or birds in hybridization. Even the obvious and superficial aspects of the case have been thus far largely unknown.

It is impossible here to enter into any adequate discussion of the literature of specific hybrids.[3] One familiar assertion, which was heard more frequently formerly than now, was to the effect that specific char-

acters tended to blend permanently in hybridization, while varietal characters were held to mendelize.[4] In recent years, many have disputed the reality of this distinction. Heribert-Nilsson,[5] for example, who has conducted extensive experiments in hybridizing willows, is led to the conclusion that even widely distinct species of these trees differ by "a surprisingly small number of factors, but that these factors influence all the organs of the individual" (p. 113). In Heribert-Nilsson's experiments, a close approach to one of the parent forms—at least in some of its most conspicuous features—was sometimes obtained from a very limited series of F_2 hybrids.

The present studies make it plain that no such account would hold true of the subspecific characters of *Peromyscus*. Most of the elements comprised in the total subspecific complex have been found to be independent of one another in inheritance. Furthermore, no single character of the complex behaves in obvious mendelian fashion. If these characters depend upon mendelian unit factors at all, they are, in every case, dependent upon rather large numbers of cumulative ("multiple") factors, which segregate independently of one another.

The present case appears to be more nearly comparable with certain of those described by Phillips[6] for hybrids among birds. From crosses between the mallard and the Australian duck "very slight segregation" was noted among 15 F_2 males, the "most extreme mallard type" scarcely differing from the F_1 individuals. In crossing the mallard and pintail ducks (a generic cross), "the smallest possible amount of segregation was found, both in the straight F_2 generation [16 males] and in back-crosses with the pintail male." Also in a somewhat more extensive series of crosses between the gold pheasant and Lady Amherst pheasant, "The F_2 generation . . . . . is merely a repetition of the F_1, but with the extreme variates slightly extended."

On the other hand, in crosses between the mallard and Florida duck, from which 38 F_2 males were obtained, Phillips records the occurrence of 2 nearly pure mallard types and 3 nearly pure Florida types. Some other crosses yielded decided, though rather less pronounced, appearances of segregation in respect to various specific color markings of the male plumage.

Phillips, like most recent geneticists, views the cases which show clear-cut evidences of segregation as the typical ones, regarding the condition of the others as due to the complexity of the factorial differences. An alternative interpretation, of course, is to suppose that we have all gradations between a complete and permanent blending of characters,[7] and a practically complete segregation of these. More evidence is certainly necessary before we are entitled to choose definitely between these two alternatives.

Further evidence of the unwisdom of allowing oneself to be stampeded at the present time is derived from the recent experiments of J. W. H. Harrison upon lepidoptera.[8] This writer, who, a few years ago, was an ardent supporter of the "multiple factor" hypothesis, has more recently been led to believe that unit characters may be changed as a result of crossing. Harrison holds "that in species and race-hybrids this gametic blending or contamination is more prone to occur than in crosses between varieties of the same species." This view he bases, in part, upon "the disparity between the enormous fluctuation of the melanism, even to its actual disappearance, in the F_2 *crepuscularia-bistortata* hybrids [a specific cross], and the uniformity of the melanics in the F_2 *crepuscularia-delamerensis* mongrels [a varietal cross]."[9]

The experiments of Detlefsen[10] in crossing the domesticated guinea-pig with a wild species of cavy (*Cavia rufescens*) yielded many results of interest, some of which the author regards as evidence of mendelian segregation.[11] Thus the "agouti" (banded) character of the hair displayed characteristic differences in the two species used, and Detlefsen believes his evidence to prove that the two types of agouti are allelomorphic to one another, the wild type being recessive. One circumstance, however, may lead one to question whether the difference depends upon stable factors, which cannot be changed by crossing. The "wild" agouti condition—at least in some lines—became continually reduced by the successive crossing of these hybrids with non-agouti varieties of the guinea-pig. Since no such reduction is known to follow from the continued crossing (and back-crossing) of agouti guinea-pigs with non-agouti ones, may it not be that such a dilution is rendered possible by the fact that, in the former case, the allelomorphs came from distinct species? Is not this perhaps just such a "contamination" as Harrison has described in the case of specific crosses?

As regards bone measurements, we learn that "there is little, if indeed, any evidence of segregation and recombination of factors for size in these crosses" (p. 71), although the parent species differ considerably in size. Also, "the differences in skull shape between the wild and tame were blended in the F_1 generation. In later generations [of back-crosses with the guinea-pig] all traces of the pointed, wild skull shape were gradually lost" (p. 77).

While many results from specific hybrids could doubtless be cited which afford more convincing evidence of mendelian segregation than the foregoing, we are, I think, forced to the conclusion that any attempt to universalize this principle is at present dogmatic and premature.[12]

[8] The results of these studies will be published in full in *J. Exper. Zoöl.*

[9] Sumner, F. B., *Amer. Nat.*, Jan.-Feb., 1923.

[2] Sumner, F. B., and Huestis, R. R., *Genetics*, Sept., 1921.

[3] Almost nothing has been done in the way of hybridizing *subspecies*. But after all subspecies do not differ in any essential way from species. Whether or not two groups of mammals or birds are regarded as species or subspecies depends upon whether the intergrading forms have been preserved. The extremes are often more widely distinct than two "good" species.

[4] De Vries, H., *Species and Varieties*, Lecture IX.

[5] *Festskrift utgiven av Lunds Universitet*, **2**, No. 8, 1918 (1–145).

[6] *Genetics*, July, 1921.

[7] I will not say of factors, since this mode of expression would concede the universality of the factorial scheme of heredity, a view which I regard as quite unproved at present.

[8] *J. Genetics*, Feb., 1920, July, 1920.

[9] July, 1920, p. 82.—It should be noted that the uniformity last referred to is not a uniformity of the F_2 generation as a whole, but a uniformity of the *melanic individuals* within that generation.

[10] *Carnegie Institution, Publ.*, No. 205, 1914.

[11] Unfortunately the F_1 hybrids were sterile inter se, so that, for later generations, Detlefsen was restricted to continued back-crosses between F_1 animals and guinea-pigs.

[12] NOTE. At the time of preparing this paper, I was not acquainted with Castle's later results on size-inheritance in rabbit crosses, *Carnegie Institution, Publ.*, No. 320, 1922.

SETS OF CONJUGATE CYCLES OF A SUBSTITUTION GROUP

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1. The importance of noting the sets of conjugate substitutions of a group is frequently stressed in the literature of group theory but little attention has been given to the importance of noting the sets of conjugate cycles involved in the substitutions of the group. While the number of the sets of conjugate substitutions of a transitive group of degree n depends on the group, and for the various possible groups of degree n this number may vary from a number which is much less than n to one which is much greater than n, the number of the sets of conjugate cycles is an invariant for all of these possible groups, being always equal to $n-1$. This fact is contained in the following general theorem: *The number of the conjugate sets of cycles in every substitution group of degree n is $n-k$, k being the number of the systems of intransitivity of the group.*

A proof of this theorem may easily be obtained from the following known theorems: The average number of letters involved in all of the substitutions of group of degree n is $n-k$, k being the number of its systems of intransitivity; and the number of letters contained in all the conjugates of a cycle involved in a group, if each of these conjugates is counted as many times as it appears in the substitutions, is equal to the

order of the group. While the theorem noted at the close of the preceding paragraph is a direct consequence of these two theorems it seems sufficiently useful and elegant to deserve special emphasis.

2. To exhibit the fundamental importance of the theorem in question as regards the study of substitution groups we shall employ it to prove one of the oldest theorems in the theory of substitution groups; viz., that there is no four valued rational function on five letters. This is equivalent to the theorem that there is no substitution group of degree 5 and of order 30. To prove this theorem it may first be noted that if such a group existed it would involve 6 subgroups of order 5 since a subgroup of order 5 can be transformed into itself by only 20 substitutions on 5 letters. As a subgroup of order 5 could be transformed into itself by only its own substitutions in the supposed group of order 30 this group would involve at least four sets of conjugate cycles of order 5. The total number of sets of conjugate cycles in a group of degree 5 cannot exceed 4 according to the theorem under consideration. Hence the supposed group cannot exist since it would also involve cycles of orders 2 and 3 according to Sylow's theorem. This also proves that there is no 24 valued rational function on six variables.

3. Every set of conjugate cycles of a transitive group involves all the letters of the group. A necessary and sufficient condition that such a set involves each letter only once is that the substitution formed by the set is commutative with every substitution of the transitive group. In particular, if a group is regular each of the sets of conjugate cycles involved in its substitutions constitutes a substitution of the conjoint of this regular group. A substitution which is commutative with every substitution of a transitive group is not necessarily found in this group but all the cycles of such a substitution must appear therein. In particular, a regular group and its conjoint involve the same cycles. A non-regular transitive group of degree n must always involve at least $n/2$ sets of conjugate cycles such that each set contains every letter of the group more than once since the number of substitutions which are commutative with every substitution of the group is equal to the number of letters omitted by the subgroup composed of all the substitutions which omit one letter of the transitive group. A necessary and sufficient condition that every letter of the transitive group appears exactly twice in every set of its conjugate cycles is that the group involves a regular abelian group of index 2 and of odd order, while the remaining substitutions are of order 2.

4. A limitation of the theorem noted near the end of the first paragraph is that it relates directly only to substitution groups. It is for this reason probably that the study of sets of conjugate cycles has received less attention than the study of sets of conjugate substitutions. In view of the fact that the theories of abstract groups and of substitution

groups are so intimately connected this limitation is not so serious as might at first be inferred. In fact, the theorem can be used to advantage in the study of primitive roots of numbers and of the exponents to which numbers belong with respect to a modulus which is a power of 2. The most obvious direct use of the theorem is, however, in connection with the study of the substitution groups of low degrees as may be inferred from the illustration given in section 2.

[1] Netto, E., *Crelle J. Math., Berlin*, **103**, 1888 (321–336).

LEUCOCYTIC SECRETIONS

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Although leucocytes have always been considered as gland structures, very little is known of the nature and functions of their secretions.

1. The only way of studying these secretions was to grow leucocytes in a medium of known properties and to examine the modifications of these properties under the influence of the living cells. When a film of leucocytes is cultivated on large mica plates under certain conditions, they grow like bacterial colonies for a few days, and a sufficient amount of serum can be obtained from the medium for the necessary tests. The method is far from perfect because the secretions are mixed with the serum and accumulate in the medium where they undergo partial destruction. Hence the serum can only give an idea of some of the qualities of the secretion although not of their quantity. In the experiments made recently by Ebeling and myself, an attempt was made to detect in the fluids extracted from the cultures of chicken leucocytes the production of substances acting on homologous fibroblasts and on sheep and rabbit erythrocytes.

A comparison was made of the media containing leucocytes and of the media containing no leucocytes. The growth of homologous fibroblasts was always more active, and the hemolysis of foreign erythrocytes often more marked in the serum from the leucocytic cultures than in that from the media incubated without leucocytes. The amount of leucocytic secretions was certainly greater than was detected, because the growth promoting substances are slowly destroyed at a temperature of 38° C. The changes observed in the properties of the fluid from leucocytic cultures must be considered as due to the presence activating substances set free by the leucocytes which did not disappear from the medium under the influence of incubation.

Then we investigated whether leucocytic secretions are increased under the influence of an antigen. Casein in a concentration of 1/1000 slightly reduces the rate of growth of chicken fibroblasts *in vitro*. After casein, in this concentration, was added to the medium containing leucocytes, the amount of substances activating the fibroblasts and destroying the foreign erythrocytes was increased. There was no parallel increase of the hemolytic action of the culture fluid upon foreign erythrocytes. This immediate reaction of the leucocytes is probably a first response to an antigen and precedes the production of specific substances.

2. We then attempted to find whether growth activating substances are secreted by leucocytes *in vivo* as well as *in vitro*. If leucocytes set free such substances in the humors of the organism, the interstitial lymph or the exudates where they accumulate must acquire the power of accelerating cell multiplication. This hypothesis was submitted to several experimental tests. It is known that extracts of adult connective tissues have but a slight activating action on pure cultures of fibroblasts. But when connective tissue taken from a focus of aseptic inflammation, produced by injecting diluted hydrochloric acid into fragments of sponge placed under the skin, was extracted with Ringer solution, the extract acquired the power of stimulating the rate of multiplication of fibroblasts. There was no doubt that inflamed connective tissue contained substances capable of increasing the rate of cell division. Similar experiments were made with peritoneal exudate. When an exudate containing many leucocytes was added to pure cultures of fibroblasts, the rate of cell multiplication increased very much. Undoubtedly leucocytes *in vivo* set free growth activating substances in the tissues and fluids where they accumulate.

3. Leucocytic secretions were found to lose their activating power after they had been heated at 56° C. The growth promoting substances which they contain appear to be as unstable as those of aqueous extracts of leucocytes, embryonic and gland tissues, and they are probably of the same nature. It is known that the substances contained in certain tissues which greatly activate the rate of cell multiplication may be destroyed in two days at body temperature, in half an hour at 60° C., and also by shaking. Their activity is greatly decreased if they are filtered through a Berkefeld filter, and lost entirely if a collodion filter is used. They precipitate with the proteins by alcohol and the precipitate dissolved in Ringer solution has almost the same activating power as the original extract.

4. The preceding experiments have brought to light two facts: first, the production *in vitro*, either spontaneously or under the influence of a foreign protein and *in vivo* under the influence of an aseptic inflammation, of substances which greatly activate the multiplication of homologous fibroblasts and are analogous to the growth activating substances already

found in embryonic and gland tissues; second, the production *in vitro* of substances which increase the natural hemolytic power of serum on foreign erythrocytes. It is probable that these secretions play an important rôle in the organism.

5. The secretion by the leucocytes of substances increasing the rate of multiplication of homologous fibroblasts suggests the hypothesis that leucocytes bring to inflamed tissues or to those in the process of regeneration the substances which are necessary to rapid cell division. This supposition is by no means new, as Renaut taught long ago that the main function of the white blood corpuscles was to bring to the fixed cells of the tissues the substances needed for their nutrition. The growth activating substances that are found in inflamed connective tissue and in peritoneal exudate are certainly capable of increasing locally the proliferation of homologous cells. An experimental proof of this was given by the result of injecting embryonic tissue extracts under the skin of chickens. The adult subcutaneous tissue reverted to a young type and, when cultivated *in vitro*, gave rise to active colonies of fibroblasts. We can assume that, under certain conditions, leucocytic secretion may cause the resumption of the activity of cells which are in a resting state. In the adult and old organisms, the tissues have ceased to grow and the plasma has acquired marked inhibiting properties. However, even in extreme old age a wound or a fractured bone always heals. This fact could be explained by the hypothesis that leucocytes bring to adult tissues the substances which they need for regeneration. This hypothesis is subtantiated by the observation that the initiation of wound healing seems to depend on the coming of the leucocytes. When they are missing, as happens when the wound is protected against all outside irritation, cicatrization is greatly delayed, and even does not occur. On the contrary, irritants such as staphylococci, turpentine, or aseptic gauze start cicatrization in less than two days. The only common characteristic of these irritants is to determine the migration of the leucocytes from the vessels to the surface of the wound. There may be an analogy between this phenomenon and the gathering in *Tubularia* of endodermic cells at the end where a new polyp is about to be formed. According to Jacques Loeb, the substances given off by these cells would be responsible for polyp formation. The leucocytes could then be considered as storing away substances characteristic of embryonic tissues and as endowed, during the entire life of the organism, with a growth promoting function.

If leucocytes *in vivo* set free their secretions in the blood stream, they should bring about important changes in the action of the serum on the tissue cells. It was found by Ebeling and myself that plasma and serum from an adult or an old animal have a marked inhibiting action on homologous fibroblasts. The rate of growth of pure cultures of fibroblasts in

serum of animals of different ages decreases progressively as the age increases. In the course of life, the serum becomes progressively more inhibiting for homologous cells. This property of serum manifests itself *in vivo* by the decrease of the rate of healing of wounds. The effect of heat, shaking, etc., on serum leads us to suppose that its growth inhibiting power is due to the antagonistic action of two substances, one growth promoting and thermolabile, and the other growth inhibiting and thermostabile, the activating substance being weaker in its effect than the inhibiting one. It is probable that the activating substances which disappear from the heated serum are secreted by leucocytes and gland cells. An increase of leucocytic secretion would diminish the inhibiting action of serum on homologous fibroblasts, while a decrease of the secretions would increase its inhibiting effect. The strong inhibiting action of serum in old age would be due partly to a reduction in the amount and activity of substances secreted by leucocytes and tissue cells.

The addition of a foreign protein to leucocytic cultures brought about a decrease in the inhibiting action of the serum on homologous fibroblasts, that is, an increase of the growth activating substances. This response of the leucocytes to an antigen possibly differs from the specific reaction which takes place later. If leucocytes behave in the organism as they do *in vitro*, we may assume that before the appearance of antibodies they respond to the presence of an antigen by setting free growth promoting substances. This immediate reaction of leucocytes and the production of substances which activate homologous cells might be partly responsible for the results observed in the treatment of certain diseases by the injection of foreign proteins.

6. Leucocytes are supposed to be, as is well known, the source of the substances which protect the organism against infection. Some years ago, it was found by Ingebrigtsen and myself that bone marrow cultivated *in vitro* responds in four days to the presence of foreign erythrocytes by the production of hemolysin. In the experiments made recently by Ebeling and myself, the serum was removed from the cultures after 48 hours and its natural hemolytic power on foreign erythrocytes was found to be increased. It appears, therefore, that the complex sensitizer alexin which is responsible for natural hemolysis is secreted *in vitro* by leucocytes and that growth activating substances and natural hemolysins are set free at the same time. *In vivo*, the variations of the action of serum on homologous fibroblasts and foreign erythrocytes are also parallel. It was found recently by Ebeling and myself that heat and shaking increase the inhibiting power of serum on homologous cells and, at the same time, decrease its hemolytic action on foreign erythrocytes. While serum from blood was a better medium for homologous fibroblasts than serum from plasma, it was also more toxic for foreign cells. Evidently there is

a relation between the production in the serum of growth activating substances for homologous cells and that of alexin and antibodies. But it is not possible as yet to determine the nature of this relation. It seems probable that a mechanism which stimulates cell activity within the organism is identical with that which opposes foreign proteins and bacteria.

DROWNED CORAL REEFS SOUTH OF JAPAN

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1. The reef-encircled, mountainous islands of the coral seas are protected by their reefs from the attack of strong ocean waves and are as a rule characterized by sloping spurs between embayed valleys. This means that the islands have been more or less submerged during or after their erosion, and that their reefs have sheltered their shores from abrasions during the submergence.

2. Clift islands in the coral seas are exceptional. Whether they are still undergoing abrasion, like Reunion in the Indian ocean, whether they have been partly submerged since abrasion but so recently that they have no reefs around them, like the Marquesas islands in the eastern Pacific, or whether their post-abrasional submergence is remote enough for the later formation of a fringing reef like that of Tutuila in the Samoan group or of a barrier reef like that of Tahiti in the Society group, they all appear to have been clift by wave attack during an early phase of their history when reef growth was for a time wanting. The absence of reefs at that time appears to have been caused not by unfavorable climatic conditions, but by the active discharge of detritus from non-embayed valleys, whereby a sheet of shifting cobbles, gravel and sand was spread over the cliff-base rock platform with the result of preventing the establishment of reef-building corals.[1]

3. Islands outside of the coral seas are usually rimmed with cliffs, $E'F'$, figure 1; and a shallow, wave-cut-and-built submarine platform, $E'D'$, stretches seaward for the cliff base, unless submergence has taken place since the time of cliff and platform cutting. The breadth of the platform may be from three to six times the height of the cliff. The recession of the rimming cliffs under the attack of strong waves is faster than the deepening of the islands' valleys; the valley mouths, Y', therefore hang in the cliff face above sea level, and the shore line is of a relatively simple, non-embayed pattern. Tristan da Cunha in the South Atlantic is a typical

example of these clift islands, except that since its cliffing it has been a little tilted to the southeast, so that the cliff-base platform is slightly emerged along its northwestern side. Islands in high latitudes that have been glaciated, like the Faroe group in the North Atlantic and Kergueleneland in the South Indian ocean, are not here considered.

4. The heads of the valleys, $A'V'$, in these mountainous, cliff-rimmed islands must lie much higher than the hanging mouths of the valleys, because the valleys in such islands have a rapid fall; and the valley mouths in the cliff faces must hang somewhat above the cliff-base platform, for the reason above noted. Hence the valley heads must be doubly high above the platform. The smaller a clift island becomes by the recession of its cliffs, the shorter and weaker will be its streams, and the less able will they be to cut down their valleys to sea level while the cliffs are retreating under strong wave attack; the mouths of the valleys will therefore continue to open high above the cliff base. In a very late stage of island consumption, the valley heads will appear only as small upland depressions in the island crests. In the latest stage, the uplands will be wholly consumed, not even the valley heads will remain, and the island will be reduced to a stack, in which the cliff-tops meet in a sharp crest or peak. Balls pyramid, between Australia and New Zealand, is an extraordinary example of this kind; its height is 1816 feet, and the smaller diameter of its base is of somewhat less measure.

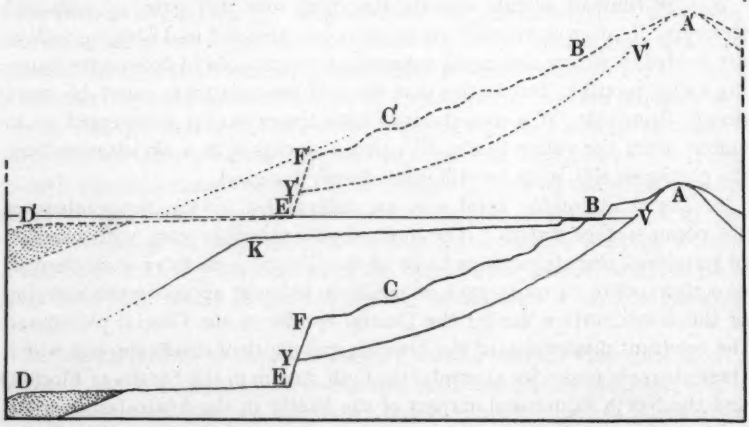
5. Cliff-rimmed islands outside the coral seas will gain an embayed shore line if, after shore cliffs are more or less abraded and hanging valleys are eroded, a strong and rapid submergence of the island drowns the hanging valley mouths; but in this case the cliff-base platform must be more deeply drowned. If a mountainous island were so far submerged as to embay even the valley heads, BV, thus reducing it to a skeleton outline, the platform, ED, must be still more deeply drowned.

6. The limits of the coral seas are determined by the temperature of the ocean surface waters. The limits should therefore vary with changes of terrestrial climate, such as those of the Glacial period; or with changes of certain ocean currents, such as might be brought about by the lowering of the ocean surface during the Glacial epochs of the Glacial period and the resultant diminution of the breadth and depth of straits through which these currents pass: for example, the Gulf stream in the Straits of Florida, and the North Equatorial current of the Pacific in the Australasian archipelago.

7. The Riu Kiu and the Bonin islands south of Japan have recently been hydrographically surveyed in much detail by the Japanese government, and the resulting large-scale charts have been reproduced by our Hydrographic Office. A most interesting body of facts is thus made available for home study. The islands of the Riu Kiu curve are mostly

composed of continental rocks.[2] The Bonin islands appear to be volcanic. Some of the islands bear elevated reefs and are reef-encircled. Others, lying a little farther north, are now free from sea-level reefs or possess at most only narrow and discontinuous fringing reefs. Oshima and its smaller neighbor Kakeroma-Shima, at. $29^1/_2°$, in the Riu Kiu curve, and the Beechey islands (Ototo-, Ani-, and Haha-jima) in the Bonin group, lat. $26^1/_2°$–$27°$, are good examples. These islands therefore lie just outside or on the margin of the coral seas of today. Their shore line is peculiar in resembling that of the embayed islands of the coral seas rather than that of the clift islands of the cooler seas. They are of skeleton-like form, having an irregularly serrated, mountainous backbone, from which short and sharp-crested, rib-like spurs, *AB*, figure 1, pitch down rapidly between well-opened bays, *BV*, that occupy interspur valley-heads, *AV*, of steep fall. This means that the islands gained a mature or late mature stage of subaerial erosion while their now visible spur ends were, for some reason, protected from prolonged abrasion by strong ocean waves. The spur ends are sometimes moderately clift; if a shallow bank occurs at the cliff-base it is very narrow.

8. Protection of the present spur ends from prolonged abrasion would have been afforded if the islands had formerly, while suffering erosion, been much more emerged than they are now, so that their summit slopes, *AB*, figure 1, and a considerable part of their now submerged slopes, *BC*,



stood above sea level in such an altitude as *A'B'C'*. But in this case a rock platform, *D'E'*, backed with cliffs, *E'F'*, must have been cut and built around the shore line at a much lower level than that of the open valley heads, *A'V'*, as explained in Section 2; and the platform must have been relatively broad, for the time required for the widening of the valley heads

to the breadth indicated by the present open embayments must have been long. Hence in the present position of the islands, the broad platforms ought to be deeply submerged, as at *DE*.

9. As a matter of fact, the islands here considered are surrounded by simple or benched banks, *BK*, of a considerable total breadth but of moderate depth. The depth of the banks is indeed so small that it does not seem possible for them to represent the platforms that must have been abraded if the islands were exposed to strong waves during the long time of greater emergence while the valley heads were widening; and the breadth of the bank is so great that their margin must lie far outside of the original perimeter of the islands at the banks' level; the banks cannot therefore represent secondary platforms cut during a pause in the strong submergence by which the valley heads were embayed. Hence the supposition that protection of the now visible parts of the islands from abrasion was provided simply by greater emergence during their erosion without the aid of coral reefs, is not satisfactory.

10. The alternative supposition that the islands were reef-protected while they were suffering erosion during a time of greater emergence, and that protection by reef upgrowth continued during a relatively slow submergence of the islands almost to their present attitude will therefore be next examined. The emerged islands may have been somewhat clift during the early stages of their erosion, before submergence began under conditions outlined in Section 2. But when submergence permitted the establishment of fringing or of offshore reefs, and when such reefs grew up in the form of normal barriers as submergence progressed, abrasion of the islands slopes would be prevented. In this case, the actual skeleton outline of the islands with their well-opened valley-head embayments would represent a late phase of long-continued erosion and submergence; but inasmuch as the postulated reefs do not now reach the sea surface, their upward growth must have been recently interrupted by a rapid submergence or inhibited by a lowering of ocean surface temperature during slow submergence; and if thus inhibited, the previously formed reefs may have been since then cut away by the ocean waves, as is postulated in the Glacial-control theory. Inhibition by lowering temperature seems more probable than interruption by rapid submergence, for such inhibition is in its proper locality in the case of these islands on the margin of the coral seas, while a rapid submergence might occur anywhere else as well as here. Since the time of reef submergence, what with the abrasion and wearing down of any submerged reefs by submarine processes, inorganic and organic, what with the aggradation of any enclosed lagoon floor, and what with unimpeded abrasion on the island margin after the disappearance of the postulated reefs, the present form of the benched banks, *BK*, may

have been developed. It is to this recent epoch of unimpeded abrasion that the visible spur-end cliffs may be plausibly ascribed.

11. The banks must have been submerged chiefly by subsidence rather than by ocean rise, because their profiles vary from island to island. Around one of the Beechey islands (Haha-jima) in the Bonin group, the subsidence seems to have involved a gentle tilting, as the benching is at slightly different depths on the east and west.

12. If the absence of reefs today is due to inhibition by lowering of temperature, and if the benched banks really represent drowned and somewhat modified coral reefs, the higher temperature of the ocean hereabouts during the period of reef growth calls for explanation. The explanation may perhaps be found in a warmer climate over the whole earth of which the last Interglacial epoch gives indications: or it may be found locally and temporarily, in the deflection of a larger fraction of the North Equatorial current of the Pacific toward Japan while the ocean surface was lowered in Glacial epochs and the passage of the branch of the current that flows through the Australasian archipelago was impeded, as above suggested; in this case the Glacial epochs might have here been epochs of higher ocean-surface temperature and hence of persistent, perhaps even of extended reef growth in spite of the restriction then imposed on reef growth along other margins of the coral seas by the general lowering of terrestrial temperatures.

13. Although the title of this article includes no interrogation point, the argument of the article does not lead to a definite conclusion. The former presence of coral reefs around the islands in question seems permissible, perhaps probable, but it is not assured. Direct study of the islands themselves in place of their charts would reduce some uncertainties; but the difficulty in reaching an assured conclusion lies chiefly in the small number of islands situated just outside of the coral seas that are available for study; for although the oceans are of vast extent and although the total number of islands they contain is large, the number of islands in the critical situation here considered is very limited; moreover, of the islands thus situated, few are surveyed and sounded in desired detail. It may be added that the validity of the arguments above employed depends, not simply on the correctness of the systematic sequences of forms believed to have been developed during a cycle of island erosion and a cycle of island abrasion, but even more on the correctness of the correlation between the two sequences of forms, one of erosional and the other of abrasional origin.

[1] Clift islands in the coral seas. PROC. NAT. ACAD. SCI., 2, 1916 (283–288).

[2] S. Yoshiwara. Geologic structure of the Riukiu (Loochoo) curve, in its relation to the northern part of Formosa. *J. Coll. Sci., Tokyo*, 1901, Art. 2 (1–67). Notes on the raised coral reefs in the islands of the Riukiu curve. *Ibid.*, Art. 1 (1–14).

GRANTS FROM THE BACHE FUND

Grants from the Bache Fund of the National Academy of Sciences have been made as follows:

$200 to Professor N. E. WHEELER, Colby College. For a study of the relationship of electrical conduction in concentrated solutions.

$300 to Professor GREGORY P. BAXTER, Harvard University. For the determination of the atomic weights of Arsenic, Titanium and Germanium.

$600 to Dr. W. H. TALIAFERRO, Johns Hopkins University. For the study of the variability and inheritance of size in different species of Trypanosoma.

$500 to Professor L. L. WOODRUFF, Yale University. For a study of the significance of endomixis and of fertilization in the life history of Infusoria.

$250 to Professor ROGER ADAMS, University of Illinois. For the study of the oxides of platinum, palladium, and iridium as catalysts.

$400 to Dr. KEIVIN BURNS, Allegheny Observatory. For the determination of wavelengths of standard lines in the solar spectrum in reference to the cadmium and neon standards.

$100 to Professor OTTO F. KAMPMEIER, University of Illinois. For a monograph on the evolution and comparative morphology of the lymphatic system of vertebrates.

$650 to Professor R. R. RENSHAW, New York University. For a study of the basis of the physiological activity of substitutes of the choline type.

$400 to Professor H. I. SCHLESINGER, University of Chicago. For an investigation of the absorption spectra of inorganic compounds, particularly the oxides of sulphur and the compounds obtained by the interaction of certain salts with nitric oxide.

Applications for grants will next be considered in April, 1923, and should be filed, together with endorsements, with the Chairman of the Board, Professor Ross G. Harrison, Osborn Zoölogical Laboratory, Yale University, New Haven, Connecticut, on or before April first. Blank forms of application will be sent on request.